PROPOSALS

FOR

UTILIZING WATER POWER

IN

SOUTHERN INDIA,

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Apart from the actual amount of power obtainable from a waterfall its value, as a source of motive power, is dependent upon :—1, The constancy of the supply of water which it is proposed to utilize. 2, The convenience or otherwise of its situation. 3, The capital outlay required to render the power available and 4, The possibility of being able to usefully employ the power developed.

Briefly examining each of these conditions in view of their application to the project which the author proposes to bring forward,

1. It will be readily conceded that no matter, how great the average amount of power which might be obtained, if it is subject to extreme fluctuations, its value is very small. The keenness of commercial competition makes it absolutely necessary that the plant employed in manufacturing operations should be constantly at work, and this can only be the case when the supply of power is regular. As a general rule it is only worth while to make use of the minimum quantity of power, though in some few cases it may pay to provide the necessary machinery for utilizing the maximum power available, supplementing it in periods of deficiency by steam. In temperate climates, where the rainfall is fairly evenly distributed through the year, a comparatively small expenditure on storage reservoirs may serve to nullify the variations in the supply of water, but in tropical climates where the year is divided into wet and dry seasons the flow of water may be subject to such

extreme changes in quantity as to render it impossible to construct reservoirs of sufficient size to be of any use. Only when the power is obtained from very high falls, when a small quantity of water will yield a large amount of power, and when the configuration of the high land is such as to make it possible to cheaply construct artificial lakes or pools, is there any prospect of commercial success attending efforts to make use of the enormous quantity of power which at present runs to waste in nearly every mountainous region of the world. The hill districts of Southern India present peculiarly favourable features for the utilization of the energy stored in the water which drains from them. Elevated plateaux,—rising on the eastern slopes very abruptly from the plains, with a heavy rainfall over more than half the year, and with few entirely dry months, the construction of comparatively small dams or retaining walls will, in many instances, be sufficient to make it possible to ensure a certain minimum flow of water from them all the year round.

2. The inaccessibility or remoteness of the situation of the falls may be such that the power is of little value. The cost of opening up the country, of carriage of raw produce to, and of manufactured goods from, the site to the nearest markets may altogether outbalance the advantages which might otherwise be derived from the use of a cheap supply of power. In some few instances also climatic conditions may be so very unfavourable as to preclude any hope of being able to establish the large industrial colonies which must necessarily be provided for in any schemes for the utilization of power on a large scale. The greater the original inconveniences of the situation the greater will be the cost of remedying them, and in proportion to the outlay involved in railways, roads and means of transport must be the scale cn which the development of the water power takes place.

3. Our principal source of motive power is the steam engine, the cost of using which may be divided into (*a*) Interest on capital outlay and allowance for annual depreciation in value; (*b*) Cost of labour and superintendence; (*c*) Cost of fuel. The first is usually a comparatively small item compared with the other two, but in the case of power derived from water it is the principal item and is often so great as alone to exceed the total cost of producing power by heat engines. In England, where steam power may be generated as cheaply as anywhere, the annual value of a horse-power is about £10, so that if we assume that on the capital outlay required for the generation of power from falling water the annual charge for interest, depreciation and superintendence is 10°/₀, then that capital outlay must not exceed £100 per horse-power, otherwise it will be cheaper to use steam as a motive force. This of course is on the assumption that the situation of the water power is everything that could be desired, if it is not so then the amount of capital which may be expended on it diminishes as the disadvantages of the situation increase till the point is reached when it will not pay to use the water power at all though it cost nothing to do so. For this reason so little use has hitherto been made of the gigantic quantities of water power which run to waste all over the world. In the not very distant future it is highly probable that the electrical transmission of energy by high potential currents will effect a great change in this respect and will throw open a wide field, at present closed, for the utilization of water power.

4. But wide as that field may be, the supply of water power is so enormous that even were it possible to get it for nothing no use could be found for it. The millions of horse-power which could be obtained from Niagara would be a white elephant to the neighbouring districts, being entirely beyond the industrial needs of the population. It

is evident therefore that any proposals for the utilization of water power in Southern India, involving no question of the transmission and distribution of power over extended areas, must be equally applicable to many other places less remote unless the conditions are such that the power can be developed at such an extraordinary small outlay as to more than compensate for the disadvantages attendant on the localization of a manufacturing industry in such a place. That this is so the author will endeavour to show in the course of the explanation of his proposals, but before doing so he would like to make perfectly clear the idea which is the basis of the scheme for the utilization of the power after it is developed. As will be subsequently seen, it is contemplated to make use of a larger amount of power than has ever been attempted before and it is because this power can be profitably employed that the following proposals promised such a magnificent financial result. A manufacturing operation which can be carried on in a place far from the markets, which it is proposed to supply, can be carried on in any place where fuel is cheap, and it is therefore absolutely necessary that it should be of such a character that the cost of the power required to carry it on shall be one of the most important items in the cost of production. If then the power can be obtained at an exceedingly cheap rate, it may compensate for all other disadvantages, and the greater its amount, provided there be a practically unlimited demand for the finished product, the greater will be the prospects of commercial success. For instance, suppose that in England a steam engine of 500 horse-power is employed in the manufacture, by some electrical process, of aluminium then the cost of the power alone will be £5,000 per annum and we shall certainly not be very far from the truth if we assume that the capital outlay on engines, boilers and the buildings in which to put them is £5,000. Now, if in Southern India we can set up

the necessary plant to develop the same amount of power from falling water, which costs nothing, for one-fifth that sum, we not only start with the advantage of saving four-fifths the capital outlay, but we have a clear £5,000 a year besides. But instead of 500 horse-power we propose to deal with an average quantity 250 times as great and the situation of the source of power would have to be extremely disadvantageous in which with that is equivalent to a bonus of £1,250,000 a year, it would not be possible to engage in a business in which the total amount of material to be transported is not more than 100,000 tons per annum. Moreover, since there is a saving of four-fifths the capital outlay required for the production of the same amount of power in England, that sum becomes available for providing the best possible means for reducing the disadvantages of the site of the works to a minimum. As will be subsequently shewn, less than one-fourth this sum will be actually needed to put the site of the water power which the author proposes to utilize in direct railway communication with the three most important ports on the Coromandal Coast, Madras, Negapatam and Tuticorin. If then it be admitted that the above remarks present a fair statement of the case for water power it will be at once seen that the project that the author brings forward is one which offers great attractions for the employment of capital.

Before entering into a detailed account of the proposals, it will be well to briefly explain that the prospect is to manufacture aluminium by one or other, as shall afterwards be decided, of the now well known electrical methods. The power is to be derived from a supply of water which it is calculated will yield during four months of the year 75,000 horse-power and during the remaining eight months 150,000 horse-power or an average throughout the year of 125,000 horse-power. This amount of power will, it is believed, when

converted into electric energy be capable of producing 15,000 tons of aluminium which will be worth, at £200 a ton, £3,000,000.

Source of the water and site of the proposed works.—The Government of Madras are at the present time engaged in diverting the water of the Periyar river, which rises in the Western Ghauts and flows into the Arabian Sea near Cochin, from the Western side of the watershed ridge to the Eastern side, so as to make it available for the irrigation of a large tract of land (150,000 acres) near the town of Madura. The works which have been designed by, and are being carried out under the superintendence of the Chief Engineer, Colonel Pennycuick, R.E., consists in the construction of a masonry dam 155 feet high, whereby the waters of the river will be dammed back to form a lake having a superficial area of over 10 square miles and containing at the level of the escapes 13,299 million cubic feet of water. The water thus stored will be taken through the watershed ridge by a cutting and tunnel, having its site at a level of 113 feet above the bed of the river at the site of the dam. The quantity of water stored, which it will be possible to draw off, amounts to 6,815 million cubic feet, but as the watershed is situated in a region where the rainfall is at least 100 inches per annum, and as the area amounts to about 300 square miles, and as the rainfall is distributed over more than eight months of the year from April to December, it will be possible to draw off from the lake a quantity of water equal to 1,500 cubic feet per second from the middle of April to the middle of December, and as at the end of that time the lake will still be full it will contain enough water to deliver 750 cubic feet per second for three months and the drainage from the occasional showers which fall in the earlier months of the year will be more than sufficient to give the extra months supply which is required. The

tunnel through the ridge will be about 6,000 feet long and will deliver the water on the Eastern side of the Ghauts at an elevation of about 2,850 feet above the sea. The hills rise very abruptly on this side, so that in about a mile the water will fall some 1,300 feet, after which it will pass into the bed of the Sooroolly river which will carry it into the Vigay, from whence it is removed by means of an anicut into the irrigation canals. It is this fall of 1,300 feet immediately after the exit of the water from the tunnel that it is proposed to utilize. It is situated near Kuruvanuth, a small village at the head of the Cumbum valley, some 70 miles from Ammanayakanur, the nearest railway station on the South Indian Railway, which is 320 miles from Madras. It is evident, that if the water power is to be utilized, it will be necessary to construct a railway from Ammanayakanur to the site of the works, but this will probably have a sufficient traffic on it from outside sources to pay its own working expenses. For further information on this irrigation project, the author would refer to the selections from the records of the Government of India, Public Works Department, No. CCXV., entitled, "Papers connected with the Periyar Irrigation Project in Madras," or to a paper on the project read before the Indian Section of the Society of Arts by Colonel J. O. Hasted, R. E., on the 30th April 1891 and published in the Journal of the same Society.

Source of the Aluminium.—The compounds of aluminium usually employed for reduction by electrical methods are the oxide, Al_2O_3 and a double fluoride of aluminium and sodium, AlF_3, $3NaF$, known as cryolite. The former compound is found naturally in a very pure state as corundum, and it is manufactured by various chemical methods, chiefly from Bauxite, a mineral of which extensive deposits occur in various parts of the world. In India, and more particularly in the southern part, there are numerous deposits

of corundum which have been worked from time immemorial as a source of emery. They occur in the districts of Salem, Coimbatore, Bellary, North Arcot and Kistna, in the native state of Mysore, and further off in Hyderabad, Rewah and the Khasi Hills in Assam.* As hitherto these deposits have only been worked on a very small scale by natives who sold the corundum for manufacture into emery powder, it is not absolutely certain that they would be capable of yielding the 40,000 tons per annum which will be required. Detailed investigation can alone settle this matter, but there is every probability that this quantity could be procured if there were a demand for it. For the same reason the present prices at which it is sold would be but little criterion of the prices which would have to be paid for it when purchased by the thousands of tons. £10 per ton would probably be the maximum price and it might be considerably less. Whilst it will be undoubtedly of great advantage to obtain the corundum in India, it is by no means essential to the success of the author's proposals that it should be so procured. In America, aluminium is being manufactured on a small scale from alumina, which is imported from Germany, where it is prepared from Bauxite at a cost of about £14 a ton. As this mineral is known to exist in inexhaustible quantities in many parts of the world, notably at Beaux in France, in county Antrim, Ireland, at Breslau in Germany and in North Carolina and Georgia in the United States, there cannot be the slightest difficulty in procuring it in any imaginable quantity and delivering it at the site of the water power for not more than £20 a ton. As from the oxide at least 50% of pure aluminium can be extracted the maximum cost of the raw material will be £40 per ton of aluminium

* A brief summary of the information on the value and extent of the deposits of Corundum in India, will be found in the Manual of the Geology of India, Part III., Economic Geology by V. Ball, M.A., F.G.S. London: Trübner & Co., 1881.

produced or less than one-fifth the lowest price the metal may be expected to reach for many years.

The only other material which will be required in very considerable quantities is carbon, of which it will be necessary to procure some 20,000 tons a year. If the particular form of carbon required can be made from wood charcoal, the dense jungles which cover the Travancore hills will be able to furnish it at a very small cost, but if some harder form of carbon, such as gas carbon, is found necessary then it will probably have to be imported from England.

Railway communication with the site of the proposed works.—As a preliminary to undertaking any Engineering work at the foot of the hills it will be necessary to first construct a railway from Ammanayakanur to Kuruvanuth. The length of the line as before stated will be about 70 miles and it will have to be constructed on the metre guage, which is the guage of the South Indian Railway. Although no surveys of the proposed line, as far as the author is aware, have ever been made yet, having traversed the whole distance several times he feels confident in saying that this line will present no engineering difficulties. A ruling gradient of 1 in 100 will probably be easily attained without expensive cuttings or embankments. A few small rivers, subject however to somewhat sudden freshes, will have to be bridged, but as the foundations are not likely to prove difficult work they will not greatly add to the cost. For the first 26 miles the route is in a westerly direction to Periyakolum at the foot of the Pulneys, whence the ascent to Kodikanal is made. The ordinary traffic along this section will, undoubtedly, prove very large as Kodikanal, in spite of the difficulties experienced in reaching it, is rapidly becoming the favourite hill station of Southern India, and the construction of a railway to the foot of the ghaut will greatly increase its popularity. From Periyakolum the line will have to turn to the S. W.

up the Cumbum valley. This section, which will be about 44 miles long, will pass through several moderately large towns, from which a certain amount of traffic may be expected. A fair amount of timber is carried down this valley on bullock carts and there is not the slightest doubt, that on the completion of the Periyar Lake, with the facilities which it will afford for the water carriage of timber from the forests all round its extensive shore line to the head of the ghaut, a very considerable development of the trade will take place, which would be still greater were there railway communication from Kuruvanuth with the rest of the Presidency. The cost of the railway, including stations, sidings and rolling stock, will not be more than £4,000 a mile or £280,000 for the whole 70 miles, so that for this sum the works will be made easily accessible and one of the most important disadvantages of this situation, *viz.*, their inaccessibility will be greatly reduced. The distances from Madras, Negapatam and Tuticorin by railway will then be 390 miles, 220 miles and 194 miles respectively.

Method of bringing the water down the Ghaut.—Between the outlet from the tunnel and the foot of the ghaut there is a total fall of about 1,300 feet, but as the slope of the ground towards the bottom gradually diminishes, it will only be convenient in the first instance to utilize the upper 1,100 feet. In this way it will be possible to reduce the length of piping which will be required to about 3,050 feet, a very important matter when it is considered that the pressures in the lower portion of the pipes will reach a maximum value of 476 lbs. per square inch. The ordinary method of carrying the water down the ghaut would be to use steel pipes of a thickness gradually increasing in proportion to the head of water producing pressure. In this case the pipes might be 36 inches in diameter with a maximum thickness of $1\frac{1}{4}$ inches. Laid in position, each pipe may be estimated to cost £10,000, and

if the water is allowed to flow with a velocity of 10 feet per second, no less than 22 pipes will be required involving an outlay of £220,000. By using the fall in two stages it would be possible to reduce the weight of metal required for the pipes, but on the other hand the number of motors would have to be increased and the power generated half-way up the ghaut would have to be transmitted to the plains below by a very expensive system of rope gearing, so that no saving would be effected by the adoption of such a plan. Now, even as it was shown that whilst not in the slightest degree essential to the success of the proposals it would be very advantageous to be able to use corundum of local extraction so here, although the cost of steel piping is not at all prohibitive yet by the adoption of a somewhat novel method of carrying the water to the motors an enormous saving in capital outlay can be secured. The rock of which the hills are composed is a hard compact syenite, and judging from what has been opened out in the tunnel through the watershed ridge, entirely free from cracks and fissures. The author therefore proposes to carry the water through an inclined shaft sunk a sufficient distance back from the face of the hill to preclude any possibility of the water pressure bursting the rock open. At the bottom of the shaft would be fixed a large cylindrical steel shell of sufficient strength to resist the full internal pressure of the water and from this cylinder the pipes leading to the motors would be carried through a heading made from the outside. As a matter of precaution, rather than of absolute necessity, the author would line the shaft with a thin steel skin not more than $\frac{1}{4}$ inch thick and firmly supported all round with a grouting of sand and cement so that the pressure would be transmitted through the ductile steel to the rock itself. The principal reason for using this steel liner is to make the shaft quite water-tight and prevent any danger arising from the water forcing its way through the

solid rock under the great pressure which would exist at the base. A slight subsidiary advantage also would be the reduction of the skin friction and consequent loss of head in the passage of the water down the shaft. As nearly 3,000 feet of tunneling has already been executed in this same rock at the rate of 1/- per cubic foot, it will certainly be possible to get out the shaft with a truly circular cross section for not more than 1/6 per cubic foot, and upon this basis the following estimate has been framed as to the probable cost of bringing the water down from the mouth of the tunnel to the pipes which will conduct it to the water motors.

	£
Masonry works at the mouth of the tunnel and the head of the shaft, including valves for closing the latter and suitable provision for passing surplus water down the natural channel ...	10,000
Sinking circular shape 10 feet in diameter and 3,050 feet long at 1/6 per cubic foot ...	18,000
Horizontal gallery and pipe chamber 150,000 cubic feet at 9 pence a cubic feet ...	5,625
Steel liner $\frac{1}{4}$ inch thick, 500 tons at £20 a ton ...	10,000
Cement for grouting 700 tons at £5 a ton ...	3,500
Steel chamber at bottom of shape, 12 feet in diameter and 50 feet long...	5,000
Contingencies 10°/。 ...	5,200
Total...	57,325

From the steel chamber the water will be conducted by 30 steel pipes 2 feet 6 inches in diameter to a similar number of Pelton water wheels which, in simplicity of action and efficiency under very high falls, far surpass all other types of water motors. With a supply of 1,500 cubic feet per second, the theoretical number of horse-power available will be 187,200, and with 750 cubic feet per second 93,600. As an efficiency of at least 80% can be obtained with Pelton water wheels, the amount of power which will be available for driving the electric machinery will be 149,760 horse-power for 8 months and 74,880 horse-power for 4 months. Each Pelton wheel will be designed to give off 5,000 horse-power. It is proposed to make them 8 feet 6 inches in diameter and to run them at a normal speed of 300 revolutions per minute. The water will be delivered through nozzles $4\frac{3}{8}$ in. diameter at a velocity of about 260 feet per second on to two sets of buckets on each wheel. The peripheral velocity of the wheels will be 133 feet per second or almost exactly 90 miles an hour. This is no doubt a very high speed but as it is confidently asserted to have been on several occasions attained by railway engines, there should be no great difficulty in providing a material sufficiently strong to withstand at the same time the tension due to the centrifugal force and the tangential pressure due to the impact of the water. It is estimated that the average length of piping required to convey the water from the shaft to the motor will be about 600 feet which, fixed in position, and provided with valves to control the water supply will cost about £5 per foot run. The Pelton water wheels it is thought can be made in England, sent out and erected in their final position for £1,500 each. On these assumptions then the following is the complete estimate of the cost of the works and machinery necessary to generate the power.

	£
Shaft and steel chamber ...	57,325
18,000 feet of steel piping for conveying the water to the motors at £5 per foot run. ...	90,000
30 Pelton water wheels at £1,500 each	45,000
Total ...	192,325

On an average of 125,000 horse-power day and night the capital outlay required therefore amounts to only 31/- per horse-power or less than one-sixth the annual cost of the same in the manufacturing districts of England. No wonder then that the author considers that this supply of water power will be a source of immense wealth to those who are bold enough to make use of it to its fullest extent.

Electrical plant.—It is proposed that each Pelton wheel should be coupled up direct to a dynamo sufficiently large to absorb the whole amount of power developed. The type of dynamo to be employed the author prefers to leave to the decision of those who have some practical acquaintance with the use of the enormous currents which it will be necessary to employ in the reduction works. Similarly as regards the electrical process to be adopted the author, from a consideration of the somewhat meagre amount of information that has been published on the subject, merely makes the tentative suggestion that an electrolytic process rather than one in which carbon plays the part of a reducing agent will be preferable. Possibly however it may be found advisable to use both, and in order to make this section of the paper more complete, he has added in the form of an Appendix a brief account of the Hall Electrolytic Process as used at Pittsburgh in America and at Patricroft near Manchester and of the Cowles' Process as used at Lockport, N.Y., U. S. A. and at Milton in Staffordshire. From these it will be seen that the electrolytic process yields a very pure

form of aluminium whilst the electrical furnace is better adapted to the production of the alloys ferro-aluminium and aluminium bronze. It would be easy to produce the ferro-aluminium on a very large scale as the corundum deposits of Salem are situated at no very great distances from the extensive beds of magnetite, but in the author's opinion the manufacture of the pure metal would prove a more remunerative undertaking. It is impossible, however, from want of sufficient data to give an even approximate estimate of the cost of the dynamos, leads, reduction works and machinery and plant required to produce the aluminium and put it on the market in a commercial form. A lump sum of £1,000,000 will, in all probability, prove ample and upon that the final total estimate of the cost of carrying out the proposals is based.

	£
Preliminary Expenses	100,000
Railway	280,000
Water power...	192,325
Buildings, workshops and dwelling houses for Staff	150,000
Electrical plant	1,000,000
Total...	1,722,325

The out-put of aluminium has been estimated at 15,000 tons per annum, worth £200 a ton, and upon this basis the gross revenue would be £3,000,000 a year, from which must be deducted the working expenses, of which the following is only put forward as an approximation.

	£
Depreciation and renewals of plant...	200,000
40,000 tons of corundum or alumina at £20 a ton	800,000
20,000 tons of carbons at £5 a ton...	100,000
Salaries and wages	250,000

Stores and plant	...	... 50,000
Royalties and patent rights		... 100,000
	Total...	1,500,000

leaving a net profit of £1,500,000, which on a capital of say £2,000,000 would be sufficient to pay a dividend of 75 per cent.

In conclusion, the author desires to state that his main object in writing the above paper has been to draw attention to the value of water power when the conditions are favourable to its development. The figures which he has presented are necessarily somewhat rough, but the error lies rather in showing an excess of capital expenditure than in any understatement of what even where it to cost twice as much as has been estimated would still be a magnificent undertaking.

APPENDIX.

I.

The following account of the Hall Process is chiefly compiled from articles which appeared in "Engineering" in April and October 1890.

The principle of the process is the electrolytic decomposition of alumina by a direct and continuous method. It was adopted by the Pittsburgh Reduction Company after working for a year with a small experimental plant. The material used is an oxide of aluminium which is manufactured at Goldschmeidn near Breslau in Germany. The mineral Bauxite is fused with carbonate of soda in a reverberatory furnace. The fused mass is lixivated with water which dissolves the aluminate of soda formed in the furnace. The solution is decanted off and decomposed by carbonic acid gas whereby carbonate of soda is formed and alumina hydrate is precipitated; after repeated washings the precipitate is calcined at a red heat, the water driven off, and anhydrous alumina formed.

In carrying out the process a molten bath of various fluoride salts is used. These are not decomposed by the electric current but in the presence of it they assist in the decomposition of the alumina though the exact reactions which take place are not clearly known. At the Pittsburgh Works a series of open iron vessels or pots are placed on the floor of the melting house. The pots are of wrought iron and are lined with carbon, a depression or well being left in the bottom of each; a framework rising from above each pot serves to support a series of iron rods to the lower ends of which are attached the carbon electrodes; these bars are held in position by binding screws and are connected to the positive poles of the dynamo; the circuit is completed by conductors from the negative poles to the iron pots. Into these carbon lined receptacles a quantity of the fluoride salts is thrown. When the current is passed through this mixture it rapidly fuses but does not undergo any further change, nor any waste save that due to accidental spilling, no matter how long it may be kept in a state of fusion. Into this bath alumina is thrown and decomposition at once begins to take place. The oxygen is absorbed by the carbon electrodes, and the contents of the pots are reduced to a metallic mass which does not mingle with the fluoride bath. As the contents of each pot are run down alumina is added in small quantities, and from time to time the aluminum is ladled from the well in each pot and poured into moulds for subsequent recasting. The process is thus a direct and continuous one, involving the expenditure of a large amount of electric energy, but one into which the action of heat, beyond that necessary to fuse the fluoride bath and the alumina, does not enter. The metal is afterwards remelted and cast into ingots which it is claimed consist of 98·5 per cent. of pure aluminium. At Pittsburgh about 500 horse-power is continuously employed in the production of 375 lbs. of metal per day. The alumina costs 5 cents a pound but

as it contains 54 per cent. of aluminium, nearly the whole of which is reduced, only two pounds of alumina are required to produce one pound of metal. The cost of the fluoride bath is merely nominal, the first cost of the materials being insignificant and the amount required, for making good waste, *not exceeding 5 lbs. for each pot per week.* The carbons used for the electrodes are made from the products of the imperfect combustion of natural gas in closed chambers, the powder formed being compressed into blocks of the required shape. The consumption of carbon is equal to the weight of metal produced.

II.

The following details as to the working of the Cowles' process are taken from a paper read by Mr. J. H. J. Dagger to the Chemical Section of the British Association at the Newcastle Meeting in 1889.

"The English works of the Company at Milton, Staffordshire, contain twelve furnaces with a 500 horse-power dynamo, built by Messrs. Crompton, and said to be the largest machine in England, and probably in the world; it furnishes a current of from 5,000 to 6,000 amperes, with an E. M. F. of 50 to 60 volts. The production of these works is 2,300 lbs. of aluminium bronze (10°/$_o$) and 1,800 lbs. of ferro-aluminium (10°/$_o$), per 24 hours, or 410 lbs. of contained aluminium.

The furnaces are rectangular in form, and are of fire-brick; into each end is built a cast iron tube, through which the carbon electrodes enter the furnace; each electrode consists of a bundle of nine carbons, each $2\frac{1}{4}$ inches in diameter, attached to a head of cast iron for a ferro-aluminium furnace, and of cast copper for aluminium bronze or alloys containing copper. This head is secured to copper rods, or 'leads,' which can be readily connected with or disconnected from the flexible cables supplying the current.

Each cable is secured to slides travelling on an omnibus bar of copper overhead, and so can be brought into position opposite the furnaces to be used. The electrodes are arranged so that it is possible, by means of a handle and screw, to advance or withdraw them from each other in the furnace. The first furnaces were lined with charcoal, but it was found that the intense heat converted it into graphite, which, being a conductor, not only meant loss of power but destruction of the furnace walls. This difficulty has been overcome by soaking the charcoal in lime-water and carefully drying before use; each particle of charcoal is thus coated with an insulating shell of lime.

Lining the furnace is the first operation; the bottom of the trough is covered with a layer of prepared charcoal, the electrodes are arranged in the furnace, and a 'former,' a sheet iron box without top or bottom, each end being arched to fit over the electrodes, is inserted; charcoal is then rammed into the space between it and the firebrick walls. This done the charge of ore, mixed with coarse charcoal and the metal to be alloyed with the aluminium, in the form of turnings or granules, is placed inside the iron box, after which this is carefully withdrawn; the space between the electrodes is bridged with some broken pieces of carbon, the charge is covered with coarse charcoal, and the furnace closed by a heavy cast iron cover, having a hole in the centre for the escape of gases evolved during the reaction; the cover is luted so as to prevent the entrance of air. The commencing current is about 3,000 amperes, and is gradually increased to 5,000 amperes; a 'run' occupies about 1½ hours. The furnace is allowed to cool; the next, ready charged, is connected with the cables, so that the process is a continuous one, the furnaces being successively charged and connected. The crude metal from the furnace is then re-melted in an ordinary reverberating furnace, a sample being taken from each run and assayed

for aluminium. The nature of the re-action which takes place in the electric furnace is not very easy to ascertain; the conditions are unlike those of any other known: the reduction of the aluminium taking place in absence of air and in presence of an enormous excess of carbon, it may be assumed that, at the intense heat of the electric arc, the ore melts and gives up its oxygen to the carbon :—

$$Al_2O_3 + 3C = 3CO + Al_2.$$

In the absence of copper the liberated aluminium absorbs carbon and is converted into a carbide of the metal. The escaping gas which burns at the orifice in the cover is almost entirely composed of CO."